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An evaluation of total iron and iron oxide ratios in lead glass and their effect on sealing

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AN EVALUATION OF TOTAL IRON AND IRON OXIDE RATIOS IN LEAD GLASS AND THEIR EFFECT ON SEALING

by

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[illegible]

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I would like to dedicate this thesis in memory of my father, Peter T. Eleftherion, for the wisdom, understanding, and honesty that he left as a legacy.

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ABSTRACT

Since the beginning of the electronics industry, glass has been widely used as an enclosure for a variety of components. It can be truthfully stated that the birth of the electronic industry would have been impossible were it not for the availability of glass. The ability of the glass to form a chemical bond between the oxides of various metals imparts a characteristic hermetically-sealed joint.

For many years, soft glass, like those in the lead-alkali group, has been used for sealing to ferrous alloys. This type of glass and the techniques for sealing have remained virtually unchanged since their inception. Under the same set of assembly conditions, atmosphere, and gas flow, the formation of a seal became somewhat constant since it was mainly dependent upon the time and temperature.

This paper covers the development of a new type of glass containing iron. The statistical evaluation indicates that there is a significant difference between the sealing times of the lead-alkali glass and the iron doped glass. It shows the effects of varying percentages of iron on seal parameters. It shows that the ratio of iron oxides determines the transmittance of the glass more effectively than the percentage of total iron. The paper includes an evaluation of the effects of this glass on seal strength.

The manufacturing aspects of this glass are discussed showing

how a new concept in sealing technology was developed. In addition, the marked reduction in product costs as a result of the change is discussed.

I. INTRODUCTION

General

For the past thirty years there has been a tremendous expansion in the use of glass for technical purposes. Hundreds of new varieties of glass have been developed along with new manufacturing techniques for glass fabrication. Glass in its every day environment often goes unnoticed. It can truthfully be said that the birth of the electronic industry would have been impossible were it not for the availability of glass. Electron tubes of all types use glass for various reasons. In most cases, it is used as an envelope to enclose electronic components. This envelope serves several very important purposes, namely:

(1) To provide a suitable gaseous atmosphere

(2) To act as a mechanical supporting structure

(3) To act as an insulator between metallic contacts

With the advent of semiconductor devices, initial desires were that gas-tight or hermetic enclosures would be unnecessary. However, it was very quickly learned that most devices suffered serious adverse effects when exposed to the influences of the open atmosphere. Today, we therefore find most high reliability devices using glass as one of its prime components. These devices would include the families of electron tubes, sealed magnetic contacts, and semiconductor diodes, transistors, and integrated circuits.

Development of new technologies continues with the introduction of special glass-like ceramics for both domestic and technical applications. More recent developments have shown that a backward glance at long time existing knowledge may introduce new and exciting developments. Such a development will be presented in this evaluation.

Glass

Glass as ordinarily recognized by the layman is a hard, brittle material that is transparent, and in addition, is a solid. Glass is a liquid at ordinary temperatures and it lacks the crystalline structure of most materials. Glasses are mixtures of several oxides some of which are known as glass formers. The three most common glass formers are silicon dioxide (S_1O_2), boric oxide (B_2O_3), and phosphorus pentoxide (P_2O_5). Other oxides such as sodium oxide (NaO) and lead oxide (PbO) are added to impart certain characteristics to the glass. In general, there are three classes of glass used in the various industries. They are:

soda-lime glass	(soft)
lead-alkali glass	(soft)
borosilicate glass	(hard)

Soda lime glass is used for windows, drinking glasses, etc. while lead-alkali glass is used more widely in the electronics field for stems, headers, and sealed contact envelopes. The lead oxide serves several useful purposes such as depressing the softening point, acting as a fluxing agent, and improving the working qualities of the glass. The borosilicate glasses are used in applications where higher temperatures and high corrosive conditions exist. The various types of glasses are shown in table 1.

APPROXIMATE COMPOSITIONS OF SOME CORNING GLASSES

Corning Code	Type Designation	Silica SiO_2	Soda Na_2O	Potash K_2O	Lime CaO	Magnesia MgO	Lithia Li_2O	Lead Oxide PbO	Boric Oxide B_2O_3	Alumina Al_2O_3	BaO
0080	Lime	73.6%	16	0.6	5.2	3.6				1	
0120	Lead	70.0	3.1	9.0				24.0		1.2	
7052	Borosilicate	68.0	1.9				8.5		15.2	8.1	2.4
7070	Borosilicate	70.0		0.5			1.2		28.0	1.1	
7740	Borosilicate	80.5	3.8	0.4					12.9	2.2	
7900	96% Silica	96.3	<0.2	<0.2					2.9	0.4	

TABLE 1

Glass Properties

Since glass is a liquid and possesses a viscosity at all temperatures, its more important properties such as annealing point, strain point, and softening point are given in terms of "poises". A "poise" being a viscosity of 1 dyne-sec per square centimeter. Another important property of glass is its thermal coefficient of expansion ($\Delta L/L$). This particular characteristic plays an important role in providing a compatible glass-to-metal seal. The various characteristics are shown in table 2.

Glass-To-Metal Sealing

As previously mentioned, glass is employed primarily as an insulator between contacts, as a vacuum tight enclosure, and as a supporting medium for various metallic elements. Glass is seldom used by itself and is most often used in conjunction with metals to which it is chemically bonded or sealed. Metal-to-glass seals are made by chemically bonding the glass to the oxide formed on the metal. The oxide is produced by heating the metal in an oxidizing atmosphere. Then, the bond or seal is made by heating the glass and metal while they are in contact. During the sealing process the glass, which is a mixture of many metallic oxides, absorbs some of the oxide from the metal. If this oxide is adherent, a strong vacuum tight bond results. In sealing, some important basic requirements must be met, and they are:

(1) The glass should wet and adhere to the metal.

(2) The linear expansion of the glass must match closely that of the metal over a wide range of temperature.

CHARACTERISTIC DATA OF COMMON GLASSES

Approximate Values for Identification and Guidance
(From Corning Glass Works)

Code No.	Description	Softening Point °C	Annealing Point °C	Strain Point °C	Working Point °C	Exp. Coeff. $\Delta L/L \times 10^{-7}/°C$
0010	Potash-Soda-Lead	626	430	393	970	91
0080	Lime	696	512	472	1000	92
0081	Lime	696	517	477	1000	91
0120	Potash-Soda-Lead	630	435	395	975	89
1710	Extra Hard	915	715	668	1190	42
1720	High Softening Point	915	715	668	1198	42
1991	Iron-Sealing	539	392	357	-	128
7040	Potash-Borosilicate	702	489	450	1080	47.5
7050	Soda-Borosilicate	703	501	461	1025	46
7052	Potash-Barium Borosilicate	708	481	438	1115	46
7055	Kovar-Sealing	718	512	472	1056	51.5
7060	Soda-Borosilicate	690	499	462	-	50
7070	Lithia-Borosilicate	-	496	456	1100	32
7295	Copper-Sealing	465	366	344	655	154
7720	Soda-Lead-Borosilicate	755	523	484	1110	36
7740	Soda-Aluminum-Borosilicate	820	563	519	1220	32.5
7750	Similar to 7740 except lower silica, higher boric oxide	704	473	432	-	40.5
7760	Soda-Lime-Borosilicate	780	523	478	1213	34
8160	Potash-Lead	627	436	394	975	91
9010	Lead Free	650	444	406	1021	88.5

Table 2

(3) The glass should not reboil when heated for making the seal.

An important factor in the sealing of glass is the heating technique that is used for melting. Most electron tubes are sealed with a gas flame technique; however if better control is desired, resistance or radiant heating techniques are used. Due to the necessity for close control in the semiconductor device and "new arts" fields, only the latter two heating techniques are used. Two problems associated with sealing are the high energy level and the long time cycle required to form the seal. Sealing time varies depending upon the geometry and size of the glass, the type of fixture material, and the heating technique employed. In most cases the glass is heated by radiation and conduction from the surrounding environment depending upon its proximity. The technique is inefficient when used on clear glass because of its poor energy absorbing characteristics. In order to justify costs, batch assembly or multiple sealing techniques are used so that the unit cost may be kept as low as possible. Sometimes, "batching" may not be possible, so individual sealing and handling must be resorted to for manufacturing.

Recently, joint development effort by the Corning Glass Works and the Western Electric Company showed that iron doping of glass increases the absorbing power of the clear soft glasses. This phenomenon results in the increased efficiency of the radiant heating source providing it contains some infrared radiation. Initial effort was started at the North Carolina Works using doped borosilicate glasses (hard) in the manufacture of resistors. Effort was discontinued until the feasibility of this principle was investigated for use in the manufacture of magnetic sealed contacts at Allentown. Joint development effort with the Corning Glass Works and the Allentown Works, Western Electric Company was initiated for iron doping of soft lead-alkali glass. This development which is still continuing covered the various aspects such as degree of doping required and the chemical conditions necessary to provide optimum sealing conditions.

The presence of iron in glass is not a new condition for the glass technologist. In the past, iron was avoided by most glass makers because of its color, and its high infrared emission and absorption. Iron containing glass therefore loses its heat content much faster, and causes it to appear of a shorter working range. The most common forms of iron of concern to glass makers are ferrous oxide (FeO) and ferric oxide (Fe_2O_3). Both of these oxides have some effect on color, however, only the divalent form provides the desirable qualities for increased sealing efficiency. Generally, known amounts of iron in the form of magnetite are added to the glass melt which is subjected to high temperautre for a lengthy time period. This causes a partial disociation of ferric oxide into ferrous oxide and free oxygen. Depending upon such conditions as:

(1) quantity of melt

(2) time

(3) furnace atmosphere

(4) glass composition

a condition of equlibrium between the divalent and trivalent iron is obtained. For a lead glass containing 3% total iron, the theoretical ratio is 2% Fe_2O_3 to 1% FeO. This imparts a characteristic dark green color to the glass and maximum infrared absorbtion. However, it should be noted that the percentage of iron is independent of the ratio of oxides. The oxide ratio as earlier mentioned is dependent upon conditions of reduction obtained during the manufacture of the glass. Varying degrees of transmittance may be obtained for a given glass by controlling the reduction process. The oxide ratios can not be easily determined by chemical analytical techniques. In order to form the divalent oxide, you must destroy the trivalent oxide. Because of this, transmittance is used as the comparison factor for oxide ratios.

This investigation will cover the various aspects encountered in evaluating iron doped glass for manufacturing. Both the resistance and infrared sealing techniques will be used for this evaluation.

II. OBJECTIVES

The development and introduction to manufacturing of iron doped glass may have a considerable effect in the various industries using glass. This effect may range from the development of additional "High Efficiency" glasses to the drastic redesigns of manufacturing equipment. The objectives of this investigation are to show:

(1) Iron doped glass is a faster sealing glass than clear glass due to its energy absorbing abilities.

(2) The percentage of iron in the glass is not the single controlling factor for greater absorbance.

(3) The mechanical strength of glass-to-metal seals is not different using iron doped glass.

First, this report will show both a theoretical and analytical analysis of determining the transmittance characteristics of a known glass containing fixed percentages of iron and iron oxide ratios. Experimental conditions for sealing and seal strength will be discussed along with a statistical analysis of these results.

The later sections are devoted to the manufacturing aspects of iron doped glass and the effects on cost. To this end, a cost comparison will be discussed from the manufacturing viewpoint.

III. EXPERIMENTAL CONDITIONS

The initial phase of this development program was to first evaluate the effects of total iron and second, the effects of the iron oxide ratios, on the following parameters:

(1) Transmittance of the doped glass

(2) Effect on sealing time

(3) Mechanical strength

Transmittance Testing Procedure

The first glass to be tested contained 2%, 3%, and 4% total iron. This glass was prepared in laboratory - type crucible furnaces. Total reduction of the iron was achieved due to the small quantity (approximately four pounds) of glass and controllable melting conditions. In order to evaluate differences among the glasses, the first comparison included an evaluation of the transmittance. At any wavelength, the transmittance of a sample is

$$T_\lambda = (1 - R1_\lambda)\ (1 - R2_\lambda)\ 10^{-B\lambda X}$$

where:

T_λ = transmittance

R_λ = reflectance at a surface

X = thickness

B_λ = absorption properties (determined by composition of glass)

The equation shows that transmittance can be varied by changing surface reflectances, by changing absorption properties or be changing thickness. Since the transmittance of each glass was desired at varying wavelengths, calculations using the theoretical equations would be somewhat impractical. Therefore, a Perkins-Elmer Spectrophotometer was used to experimentally determine the transmittance of each glass. This equipment uses a monochromatic light source for scanning across the spectrum for transmission properties.

The glass to be treated was formed into disks 15 millimeters in diameter and 1 millimeter thick. The results for the 2%, 3%, and 4% total iron were plotted as transmittance versus wavelength. The graphs are shown in Appendix A, Figure 1.

To determine the effects of varying degrees of iron reduction on transmittance, a second evaluation was initiated. Using a fixed percentage of total iron, namely 3%, curves of transmittance versus wavelength were plotted. These curves are shown in Appendix A, Figure 2. The samples obtained represent various stages of production melting during a period when complete reduction was being experimentally attempted. This problem of complete reduction became apparent during the first large volume production melt by Corning. The inability to maintain or control the reduction presented an excellent opportunity for evaluation of the effects of reduction on the transmission characteristics of the glass. Once the transmittance characteristics were established, then the effects of time could be evaluated.

Sealing Time Procedures

In order to evaluate the effects of transmission on the ability of the glass to absorb heat energy, two experimental sealing facilities were used. The first equipment utilized resistance heating techniques.

An assembly head for sealed contact manufacturing was used. The glass melting source consisted of a .050 of an inch diameter three turn platinum-rhodium coil with an internal diameter of .218 of an inch. Power to the coil was supplied by a transformer capable of delivering three volts at 55 amperes. The samples of glass to be evaluated were formed into glass tubing having a .150 of an inch diameter with a nominal wall thickness of .025 of an inch.

The sealing procedure involved placing the glass tube in position as shown in figure 1. Using a stop watch, it was possible to determine the exact point of glass flow when contacting the metal. A cobalt glass shield had to be used for eye protection during the time trials. The results obtained were categorized as to the percentage of total iron in the first group, namely 0%, 2%, 3%, and 4%. Twenty readings were recorded. The second group was classified by its transmittance characteristics determined by the iron oxide ratios. The composite data appears in Appendix B.

The second set of conditions for sealing time evaluations was obtained through the use of infrared sealing equipment. This equipment consisted of a modified resistance coil sealing head. The coils were removed and an infrared sealing lamp was positioned at the focal point of a parabolic reflector. The glass tube was located at the second focal point. The infrared bulb consisted of a 650 watt tungsten-iodide filament quartz bulb capable of reaching extreme temperatures above 2000° C. The effects of the various glasses on sealing time were again experimentally evaluated. The procedure for recording

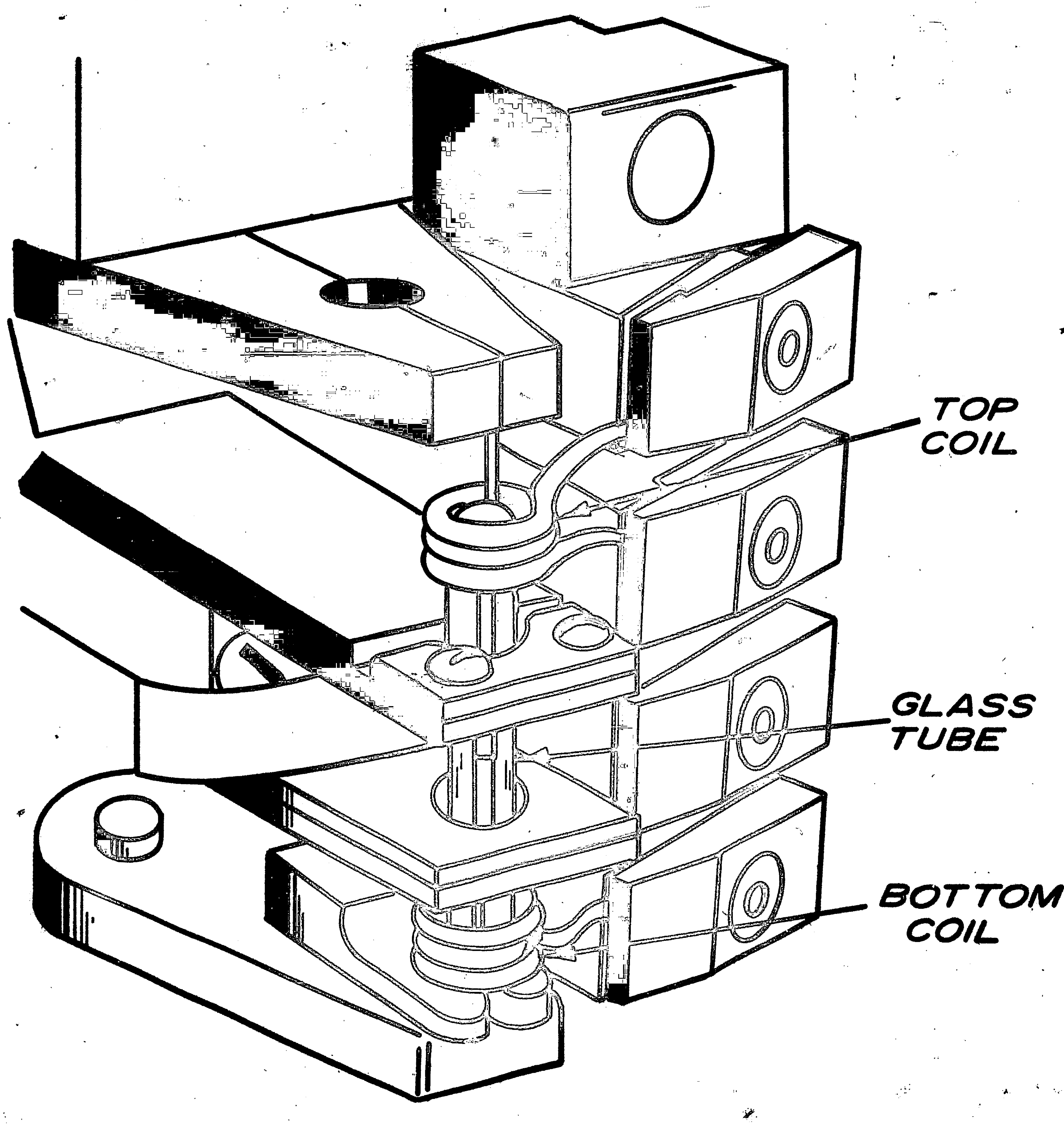


FIGURE 1.

the sealing time was similar to that followed using the resistance coil heating techniques. Both groups of glasses were tested and the results appear as part of the sealing time data in Appendix B. After the seals have been made, they must be evaluated for condiitons of stress. The procedure is outlined in the next section.

Seal Stress Procedure

Stresses are produced in glass-to-metal seals after the sealing operation. These stresses are due to the difference in the thermal coefficient of expansions of the glass and metal and also due to the rate of cooling of the seal. More rapid cooling induces higher stresses. The stresses may be either tension or compression, depending upon the factors mentioned and upon the type of seal. Glass never fails in compression; it always fails under tension. The mechanical strength of a seal can usually be determined by measuring the stress in the seal.

Due to the birefringent characteristics of glass, the stresses can be measured with a polarimeter. The polarimeter is an apparatus that gives an indication of the algebraic difference between the horizontal and veritcal stresses at a given point. The equipment used for this procedure utilizes a quarter-wave plate in conjunction with an analyzer that can be rotated. The rotation of the analyzer is directly proportional to stress. The reading of the analyzer is known as a "retardation" reading given in millimicrons. The stress can be stated as:

$$S = \frac{R}{LC}$$

where S = Stress, kilograms per square millimeter

R = Retardation, millimicrons

C = Stress optical coefficient

L = Length of light path through the glass

The retardation is generally given in degrees when stress comparisons are made between groups of glasses.

Twenty seals were made from each group of glasses using both the coil sealing equipment and also the infrared equipment. Each unit was first immersed in a liquid having the same index of refraction as the lead alkali glass. It was then possible to measure the stress in the seal using the polarimeter. The seals had a pattern as shown in figure 2. Readings for the maximum stress at each point were recorded for the top seal. There were two readings from each seal since the outer wall was in compression and a tangential stress existed at the glass-to-metal interface.

The readings were grouped by total iron percentages, transmittance properties and by sealing techniques. The seal stress data appears in Appendix C. While the degree of stress usually indicates the mechanical strength of a seal, a more positive test is the time-force test. This test defined as a creep test is described in the next section.

Creep Testing Procedure

The mechanical strength of a seal can effectively be determined through the use of a test commonly referred to as "the creep test" developed by the Bell Laboratories at West Street, New York City.

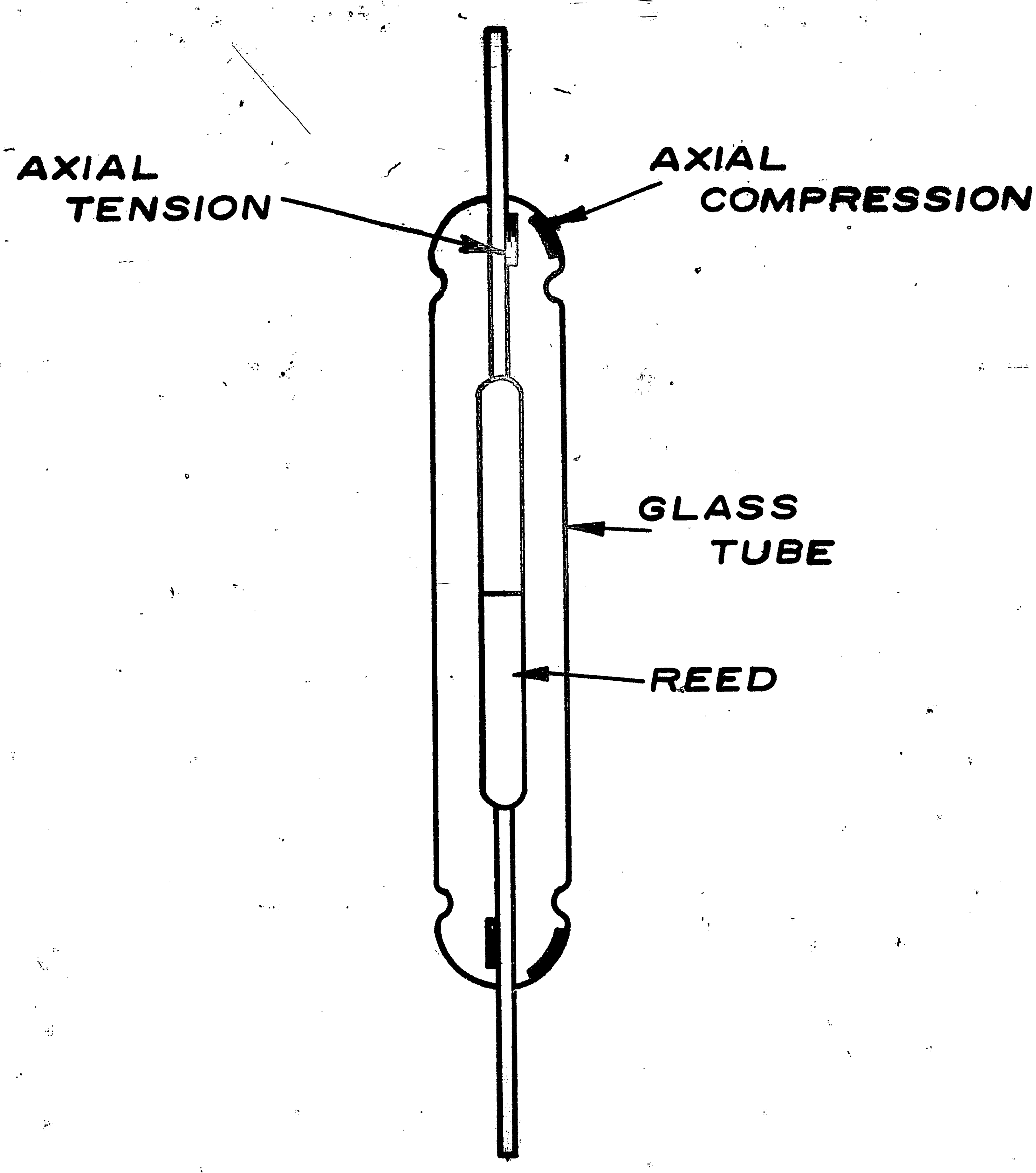


FIGURE 2

This test uses the procedure of holding the glass and applying a known force to the lead for a predetermined length of time. After removing the force, the seal is then leak tested through the use of a technique called radiflo. This radiflo technique uses the principle of applying 90 pounds of pressure to the external part of the seal by means of a radioactive gas. If the seal is defective and leaks, the gas will penetrate to the inside and can be detected with a Geiger counter.

Using the creep test and radiflo procedure, twenty units were tested from each group of glasses. The creep testing was performed with weights of three, five, and seven pounds applied for a period of three minutes. Each test was performed separately. Upon testing at three pounds for three minutes, all the units were sent to radiflo for leak detection. The units that did not fail this test were then tested at five pounds for three minutes and then at seven pounds. The data for each group is listed in Appendix D.

<u>Summary</u>

Using the tests described in this section, it was possible to evaluate the statistical significance of the data collected. The results of these evaluations are described in the next section.

IV. ANALYSIS OF EXPERIMENTAL DATA

The data collected as outlined in the previous section is summarized in the appendix section of this report. Appendix A shows the results of plotting transmittance versus wavelength for the various glasses. Figure 1 shows the comparison of the 0% to 4% total iron glasses. For comparison purposes, the wavelength of one micron was chosen. The transmittance of the 0% or clear glass is 92% over a wide spectrum. Doping of 2% iron dropped the transmittance of the clear glass to 32%. This represents a substantial decrease in the transmittance. Additional doping of 3% and 4% dropped the value to 16% and 9% respectively indicating that an increase of iron does decrease the transmittance.

The second set of curves shows the effect of iron oxide ratios on transmittance. In each case, the total iron was 3%. An increasing amount of ferrous oxide dropped the transmittance considerably. In order of increasing ferrous oxide, the glasses measured at one micron were as follows:

936FF	- 38 %
936FS	- 16.7%
936FT	- 9.4%
9362	- 6.0%

The glasses 936FS and 936FT are listed at only one wavelength. Therefore, in order to expedite the evaluation, the comparison point of one micron was again used. Results indicate that complete reduction yields the lowest transmittance. A considerable range of transmittance is obtained by varying the degree of reduction which determines the ratio of divalent to trivalent iron oxides.

The statistical results of the sealing time and sealing stress data gathered in the previous section are shown in Appendix E. Both the F test and the t test were applied. These tests were evaluated jointly because of the importance of the mean values and the variability of each run. The mean is important in both the time and the stress because this is directly related to the speed of the sealing operation as well as the strength of the seal. The variability is important in that it is an indication of the type of control obtained for each condition. This becomes quite important where high reliability devices are involved. Because of this, the F tests were compared in pairs. The number of degrees of freedom for the F test comparison was (n-1) or 19 in cases of 20 readings. The number of degrees of freedom when making t test comparisons was (n+n-2) or 20 + 20 - 2 = 38 in cases of 20 readings each.

Appendix E, table 1 shows a comparison of the statistical data from 0% to 4% total iron using the resistance coil. From 0% to 2% there is an 11.45 second difference in the average, however from 2% to 4% the greatest difference is 1.81 seconds. The time for the 4% total iron was 25.87 seconds compared to 24.32 seconds for the 3% total iron. This is believed due to the fact that the 4% has a tendency to dissipate the heat more rapidly. A comparison of the F test of the 2%, 3%, and 4% against the 0% shows significance in the standard deviation at the 0.5% probability level only in the 4% glass. A sequential comparison of 2%, 3%, and 4% shows a significance at the

1.0% level for 4% against 2% and at the 2.5% level for 3% against 4%. A comparison of the t test shows that the 2%, 3%, and 4% averages are significantly different than the 0% glass at the 0.1% probability level. The mean difference between the 2% and 3% significant at the 0.1%. The 3% glass being the faster sealing glass.

A comparison of the 3% total iron glass at varying reduction is shown in table 2 of Appendix E. The average sealing time decreases as the transmittance decreases except for the 9362 glass. This difference of 0.39 seconds is within the human error in the time measurements. In each of the four groups of glasses, none of the F tests indicated significant differences in the standard deviations. However, a comparison in reducing transmission shows significance at the 0.1% probability level in each comparison. This is due to the decreasing time.

The results from the infrared sealing time experiments are listed in table 3 and table 4 of Appendix E. Note that in the 0% glass, a complete seal was not established due to the reduced time cycle. Without a statistical comparison, it is evident that a significance does indeed exist between the average sealing time of the 0% glass compared to the 2%, 3%, and 4% glass. A significant difference between the standard deviation between the 2% and 3% glass is indicated at the 0.5% level. Significance at the 0.1% level is indicated when comparing the means of the 3% and 4% glass against the 2% glass. Note that again the 4% glass had an increasing time average similar to that indicated in the resistance heating results.

A comparison of the 936FF glass shows that a significant difference exists only between the 936FT glass at the 1.0% probability level in the standard deviation. While the FT glass has a lower spread, there is a significant difference in the mean of 8.12 seconds against the other means at the 0.1% level. This is due to the much higher transmission. As would be expected, a significant difference in the mean is also evident between the 936FS glass and the 936FT, 9362 glasses. However, it should be noted that there is no significant difference between the mean of the 936FT glass and the 9362 glass. This tends to indicate that as the transmission approaches a maximum, the average sealing time does not vary very much.

Sealing Stresses

A comparison of the resistance coil sealing stresses for both groups of glasses checked shown in Appendix E, table 5 and table 6. In the 0% to 4% comparison, there was significant difference in the standard deviation comparing all groups. However, there was a significant difference in the tension comparison of the mean of the 0% glass against the other three groups. The mean of 2.55 degrees was quite low. This is due to the much longer sealing time and slower cooling time. While the stress in tension is higher in the doped glass, critical calculations show that stress below 25 to 30 degrees is quite safe. There was no significant difference between the means of the 2%, 3%, or 4% glass in tension. A look at the compression comparison shows less significance between the glasses.

The mean of 12.05 degrees in the 0% glass compared to 13.55

degrees of the 3% glass is only significant at the 5% level. This indicates that the relative heating between the metal and reed interface is the most critical as shown in the tension comparison.

A comparison of the 3% glasses is shown in Appendix E, table 6. The 936FS glass has the lowest deviation when compared to the other groups in both tension and compression. The mean of the 936FS glass appears to be misplaced. It's transmittance characteristics indicate that it should have a lower mean than either of the last two glasses. There is no explaination offered for this. There is no significant difference in the spreads of the four glasses when comparing compression. In both stress conditions, the lowest transmittance glass (9362) had the higher mean.

Appendix E, table 7 shows the statistical results of the 0% to 4% stress levels using the infrared technique. There is no indication of significance among the spreads of the three glasses. Again, note that there is no comparison against the 0% glass since it did not seal in the maximum time of the equipment. There is a significant difference between the means of the 2% and 4% and also the 3% and 4%. The average stress level in tension was 5.6 degrees. The compression comparison tends to verify the results that little or no significant differences exist in the mean value.

Appendix E, table 8 shows the results of the varying 3% sealing stresses. The 936FF glass had the highest mean value and the greatest variance. The variation may be due to the higher transmittance and the inability of the glass to absorb the infrared energy consistently. There is little difference when comparing the 936FS, 936FT, 9362 glass.

Creep Analysis

Appendix D, tables 1 through 4 list the results of the creep test for seal strength. While there is a slight difference in the seven pound load testing, this is not cause for concern. Large amounts of data gathered at the seven pound load indicate that there tends to be a higher rejection rate. This data is being gathered in an independent evaluation using both clear and doped glass. The recommendation of this independent investigation body has defined the five pound load as the established test parameter. This is the point established as an indication of poor seal strength as shown from their testing.

V. MANUFACTURING CONSIDERATIONS

The development of iron doped glass promises to have a considerable effect on the techniques for forming glass-to-metal seals. The ability of the glass to absorb radiant energy greatly increases the efficiency of the sealing operation. The data collected comparing sealing times shows the decrease in time. Iron doped glass has "opened the door" for sealing with infrared techniques. This infrared technique would be of no value without the use of doped glass.

Perhaps a better idea of the effects of the introduction of such a glass into a manufacturing process can best be illustrated in a brief discussion of the 237B sealed contact manufactured at Allentown. This section will deal specifically with manufacturing effects while the next section will deal with the economic considerations.

The sealed contact consists of two iron-nickel reeds and a glass envelope shown in figure 2. Clear glass sealing was performed on manual heads using resistance type heating. The assembly cycle was 72 seconds; however, with the initial introduction of the iron doped glass, the assembly cycle was reduced to 50 seconds. This represented a 38% reduction in assembly time. Additional development effort was expended and a 45 second cycle is now in operation. This represented an additional increase in the output of the equipment. The only change that was necessary to convert the equipment was to introduce the proper timing gears to each head for providing the reduction. Product yields and individual parameters were comparable to equivalent product assembled using clear glass.

While a considerable time savings was achieved using resistance heating, the most significant manufacturing change was the introduction of infrared sealing. From the sealing time data, it is evident that infrared sealing can be accomplished in considerably less time than with resistance heating. Two very important equipment changes resulted from the doped glass. The first change occurred on the mechanized facilities. The mechanized machine containing 32 manual type heads assembled units for every complete revolution of the indexing table. Through the use of infrared, it was possible to add another loading station to the machine. This changed the characteristics of the machine and a unit was assembled every 180 degrees or one-half a revolution of the table. This change doubled the output of the original equipment.

The second change included a complete redesign of the mechanized assembly equipment. Instead of the 32 head machine modified to accommodate infrared, an 8 head machine designed specifically for infrared was constructed. This machine eliminated some of the problems encountered in converting the coil machines. It is planned to introduce these machines on a cost reduction basis.

The next section will deal with the effects of the glass and equipment changes on the overall product cost. While this discussion covered a specific product, the doped glass and the techniques of infrared sealing are applicable to many sealing situations.

VI. ECONOMIC CONSIDERATIONS

From the previous section covering manufacturing considerations, one can visualize the effects on product cost. In order to show more specifically how this change can affect product cost, a detailed investigation was conducted covering the various machines used in assembling the sealed contact. The machines are as follows:

1. Single-ended machine - resistance heater coil
2. Double-ended infrared machine
3. Eight-head infrared machine

The first machine is the standard machine used for clear glass assembly. The second is a modified single-ended machine adapted for iron-doped glass. The eight-head machine is a completely new concept.

Most of the products made at Western Electric are manufactured by a series of operations performed in sequence. To provide any given level of manufacturing capacity for the product, an engineer must provide facilities having a capacity that is at least equal to that level for each operation involving the shrinkage factor. Annual capacity for any facility can be stated in terms of the amount of good product that can be manufactured on that facility each hour and the number of hours available for manufacturing. This general relationship is as follows:

Annual capacity = Good units/hour x total available hours annually.

The number of good units can be subdivided into the following:

Good units/hour = EHO x Efficiency x Yield where EHO is the expected hourly output of a facility. It is based on personnel exerting normal work effort and performing such work with normal proficiency. The second factor in the equation of good units/hour is efficiency. The efficiency implied in the determination of EHO is 100%. However, in particular cases the actual efficiency may differ, being somewhat lower during facility prove-in. The third item listed is yield, and this is dependent upon the number of defective units obtained. This briefly defines the term "good units per hour".

As stated earlier, capacity is also dependent upon total available hours. In this particular study the total available hours for each machine were defined. The total number of available hours per person is 1,930 considering personal allowances. However, each machine has non-productive hours as shown below:

Item	Single-end	Double-end	8-Head Infrared
1. Set up and clean	185	185	125
2. Maintenance	200	300	140
3. Waiting time	0	0	0
4. Machine adjustment	200	100	60
Total non-productive	585	585	325
Total available hours	1345	1345	1605

It can be seen that the eight-head infrared machine due its less complex design and fewer heads (8 versus 32) provides more available hours.

The next tabulation shows the various cost factors considered in this evaluation.

SEALED CONTACT - FACILITY STUDY

Cost Factors	Single - Ended Resistance Coils	Double - Ended Infrared	Eight - Head Infrared
Machinery Initial 4 a/c	Approx. $200,000	Approx. $235,000	Approx. $50,000
Hourly Output - Machine	Approx. 1200/hr.	Approx. 2400/hr.	Approx. 900/hr.
Machine Capacity (5D - 2S)	Approx. 3,240,000	Approx. 6,480,000	Approx. 2,900,000
Machine Yield	74% (estimated)	74% (estimated)	74% (estimated)
Actual Machine Output	Approx. 2,400,000	Approx. 4,800,000	Approx. 2,150,000
People: Hd. Setter	1/2	1	1/4
Operator	1	0	0
Proc. Checker	1/2	1/2	1/4
Maint./Mach./Shift	1/2	1/2	1/4
Head Rebuild - every 5 years	$20,000	$20,000	0
Coil Cost/Mach./Year	$300	0	0
Lamp Cost/Mach./Year	0	$225	$150
No. Machines for 30 million	13	6	14
Maint. Material & Expense			
Supplies/Mach./Year	$2,000	$3,000	$1,000
Engineer Development Expense	0	$200,000	$200,000
Floor Space - Ft^2/Mach.	120	135	60
Rate of Return	30%	30%	30%

The assumed life of product and the machinery is considered to be fifteen years. A thirty percent rate of return on investment (before taxes) was used for this study. The factors for yearly charges on the facility study as shown in Appendix F are listed below:

Line 1: Machinery - Investment factor of .275 for 15 years.

Line 4: Tools - Investment factor on .397 for 5 years.

Line 9: Engineer Expense - Annuity factor of .171 for 15 years.

Line 15: Floor Space - $5.00 per square foot per year.

Line 17: Fixed Maintenance - Actual cost used.

Line 19: Other miscellaneous expense - Actual cost used.

Line 25: Total of all charges.

Line 26: Discount factor for each year of study starting with .870.

Line 27: Total of all charges multiplied by discount factor.

Line 28: Annuity factor for study period which is .171.

Line 29: Present worth times annuity factor.

The cost study was calculated for a multi-million level program per year. From the data, the following relative costs were obtained (single ended as base):

Single Ended Resistance Coil Machine	100% per 1,000 units
Double Ended Infrared Machine	41/100% per 1,000 units
Eight Head Infrared Machine	35/100% per 1,000 units

As indicated on the percentage basis, a considerable cost saving from the initial single ended machine is obtained. For a multi-million program level per year, the savings are considerable. Thus, the importnace of the iron doping becomes quite evident and quite conclusive.

VII. CONCLUSIONS

VII. CONCLUSIONS

Analysis of the data has shown that the transmittance of the glass decreases as the iron content increases. The clear glass had a value of 92% compared to 16% transmittance for 3% iron doped glass. The data also shows that varying degrees of iron oxide reduction keeping the total iron constant has a great effect on transmittance. This ratio of divalent to trivalent iron oxide is the most controlling factor as shown by the range of 38% to 6%. Increasing divalent iron oxide decreases the transmittance.

The sealing time is significantly reduced due to iron doping. The time decreased from 37.59 seconds to 24.32 seconds for 3% doping. while the infrared sealing time was 6.99 seconds for the equivalent doping. The 4% total iron glass had the lowest transmittance at 9%; however, the sealing times were higher than in any other group. This indicates that too much iron may have a negative effect.

The sealing stress data does indicate a significant increase in the tensile stress around the seal interface. The clear glass had a value of 2.55 degrees retardation as compared to 7.55 degrees for the 3% doped glass. While this increase is significant, the critical stress value from previous experiments has shown the value to be about 30 degrees. Since the 7.55 value is well below this, there is no concern because of this increase.

The introduction of this glass for manufacturing has yielded two important changes. Due to the decreased sealing time, equipment outputs have increased and simplified assembly processes are being developed. In addition, the effect on product cost has been considerable. The cost on a sealed contact unit manufactured by the Western Electric Company will drop from a 100% base per 1,000 units to 35% of the base per 1,000 units.

VIII. RECOMMENDATIONS

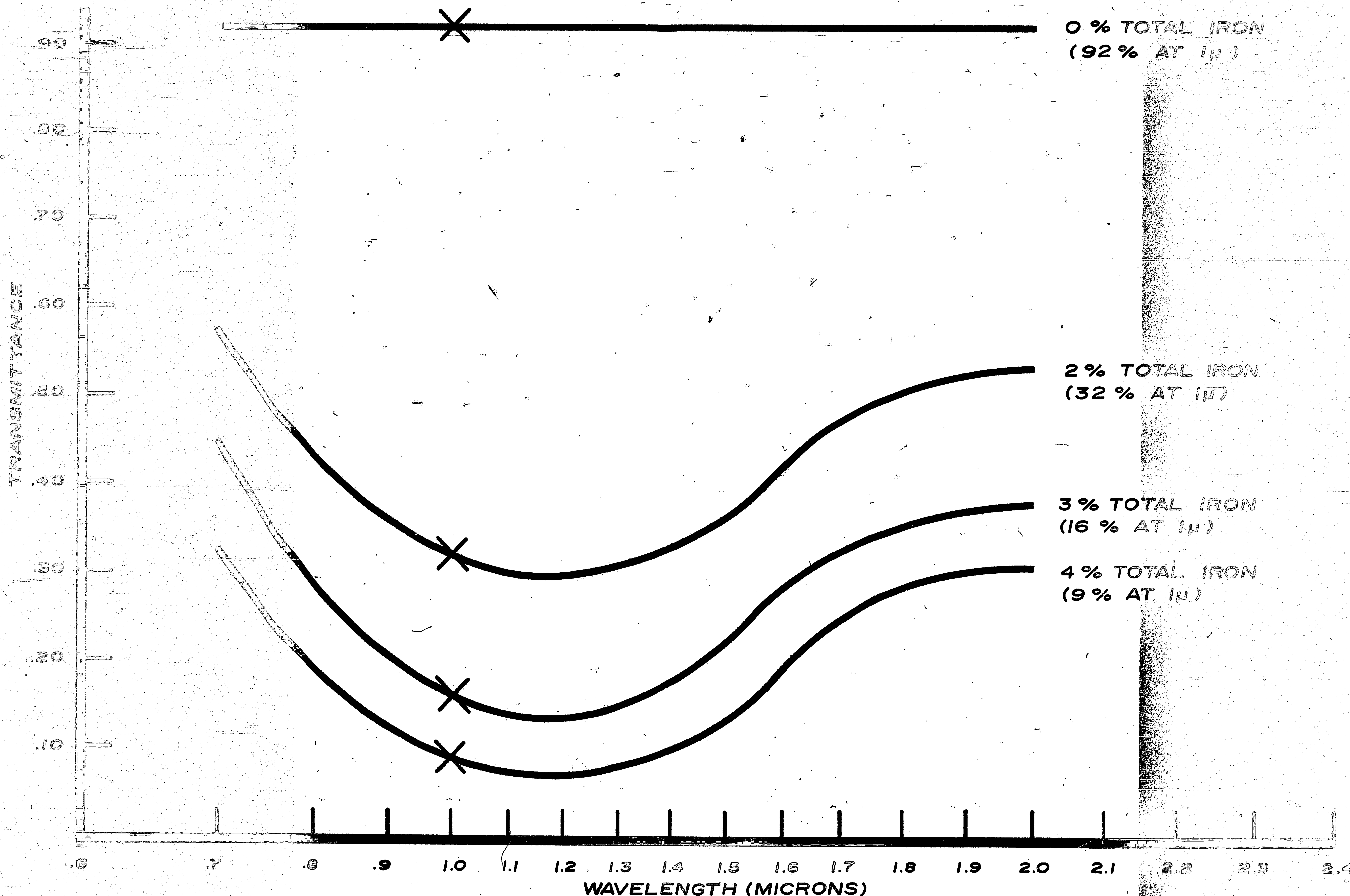
The development of iron doping of lead glass most certainly warrants further studies in the area of the interactions of total iron versus iron oxide ratios. While this report covered variations for only the 3% level, comparisons of reduction should be made for the 2% and the 4% level. By keeping the same transmittance values at each level, the interactions between total iron and iron oxide ratios may be evaluated. This could lead to the development of an optimum iron percentage and a given iron oxide ratio based on transmittance.

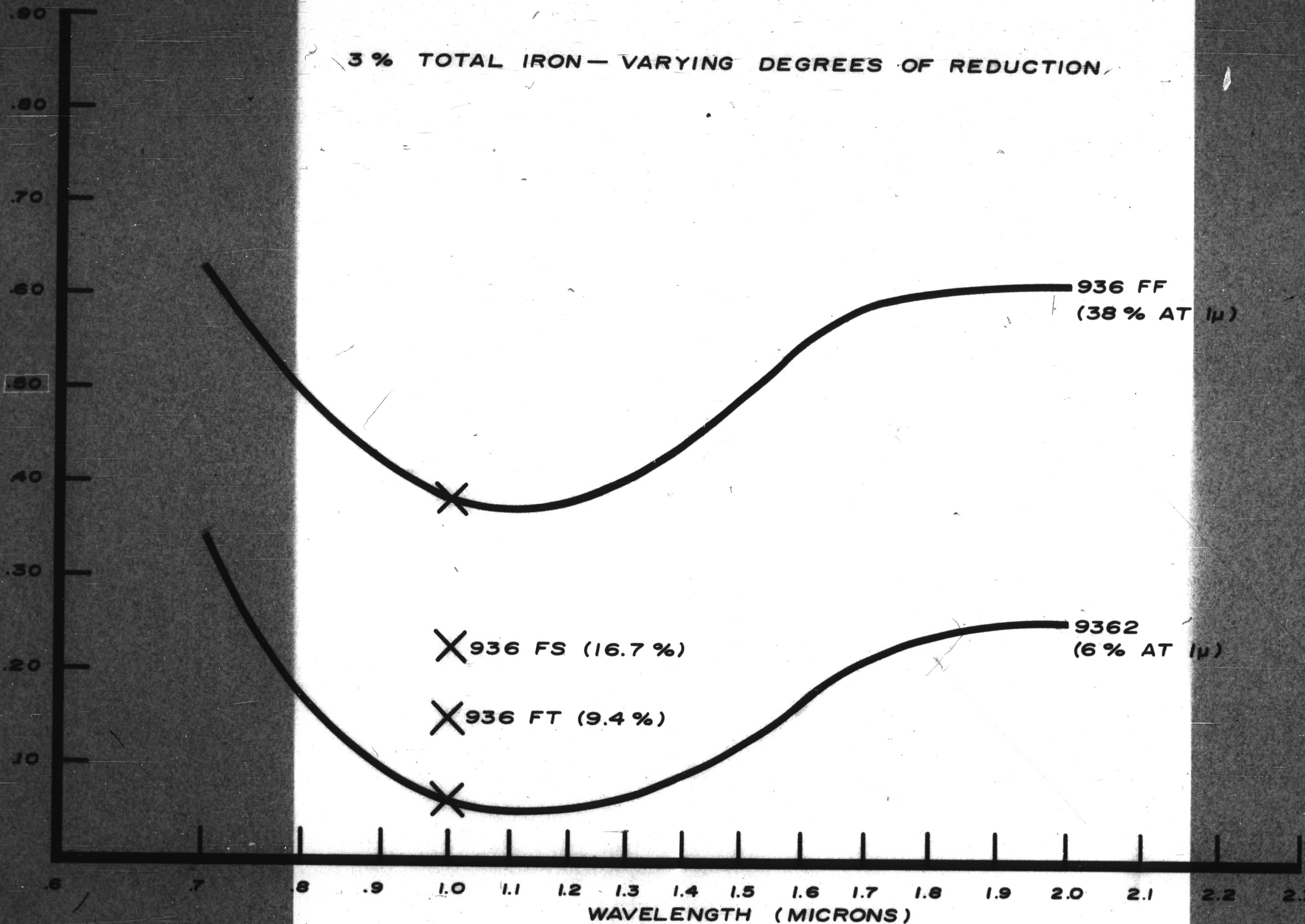
The studies that are now being conducted for doping soda-lime glass (lead free) and borosilicate glass should continue. The doped lime glass could offer the advantage of reduced cost due to the absence of lead. In addition, the vaporization of lead presently experienced with lead glass should be virtually eliminated. Doping of barium lime glass should prove to be exceedingly attractive to the lead glass users since it has annealing and strain points very close to those of lead glass.

Further effort should be exerted to determine other applications for the infrared sealing using doped glass. Areas such as terminal and stem sealing should be investigated and what are the sealing effects of using this glass in muffle type furnaces.

APPENDIX A

Transmittance Data


0 % TOTAL IRON
(92 % AT 1μ)
2 % TOTAL IRON
(32 % AT 1μ)
3 % TOTAL IRON
(16 % AT 1μ)
4 % TOTAL IRON
(9 % AT 1μ)
TRANSMITTANCE
.90
.80
.70
.60
.50
.40
.30
.20
.10
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
WAVELENGTH (MICRONS)


3 % TOTAL IRON — VARYING DEGREES OF REDUCTION
.90
.80
.70
.60
.50
.40
.30
.20
.10
936 FF
(38 % AT 1µ)
9362
(6 % AT 1µ)
936 FS (16.7 %)
936 FT (9.4 %)
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
WAVELENGTH (MICRONS)

APPENDIX B

Sealing Time Data

APPENDIX B

Sealing Time Using Resistance Coil

(Time in Seconds)

Run No.	Total Iron 0%	2%	3%	4%
1	37.0	25.2	23.6	26.2
2	35.9	25.8	23.9	26.0
3	36.2	26.9	24.8	25.5
4	36.4	25.6	23.7	25.1
5	36.2	26.9	24.9	25.5
6	38.0	25.8	23.8	26.3
7	37.2	25.9	24.3	25.4
8	39.2	28.3	24.9	26.1
9	37.3	26.7	23.5	25.3
10	38.2	25.9	25.4	26.2
11	39.0	26.1	26.0	26.5
12	39.4	25.6	24.3	25.2
13	38.4	25.3	25.2	25.8
14	38.0	26.2	23.8	26.0
15	37.6	25.8	24.2	26.4
16	38.2	25.2	24.0	25.7
17	36.9	26.9	23.9	25.9
18	37.4	26.5	24.7	26.2
19	38.0	25.9	23.5	26.3
20	37.2	26.2	23.9	25.8

APPENDIX B

Sealing Time Using Resistance Coil

3% Total Iron

(Time in Seconds)

Run No.	Code 936FF	Code 936FS	Code 936FT	Code 9362
1	27.2	26.5	24.2	25.9
2	26.5	26.3	23.9	25.4
3	26.9	25.3	25.1	24.1
4	27.1	25.1	24.6	24.0
5	27.2	25.0	25.0	25.8
6	27.0	26.0	24.4	23.9
7	26.9	25.7	23.7	25.1
8	25.9	25.8	24.3	23.7
9	26.5	25.1	24.0	25.0
10	27.1	25.1	23.9	23.8
11	26.9	24.8	24.7	24.6
12	27.0	25.0	23.7	24.1
13	25.4	25.3	23.2	24.3
14	27.3	25.1	24.1	23.7
15	27.2	25.0	23.9	24.9
16	26.7	25.2	23.5	23.9
17	26.5	26.2	23.7	24.2
18	27.3	25.7	24.1	24.4
19	25.9	25.4	23.9	23.9
20	26.8	25.3	23.9	24.8

APPENDIX B

Sealing Time Using Infrared

(Time in Seconds)

Run No.	0%	2%	3%	4%
1	--	8.3	7.1	7.3
2	--	8.5	6.9	7.3
3	--	8.3	7.1	7.1
4	--	8.3	7.1	6.9
5	--	8.5	7.3	7.1
6	--	8.5	6.5	7.1
7	--	8.5	7.1	7.3
8	--	8.5	6.5	7.1
9	--	8.4	7.0	7.1
10	--	8.3	7.1	7.1
11	--	8.3	7.0	7.3
12	--	8.2	7.3	6.9
13	--	8.5	7.3	7.3
14	--	8.2	7.1	7.3
15	--	8.5	6.9	7.0
16	--	8.2	7.0	6.9
17	--	8.4	7.0	6.9
18	--	8.3	6.9	7.0
19	--	8.5	6.5	7.1
20	--	8.5	7.0	7.3

APPENDIX B

Sealing Time Using Infrared

3% Total Iron

(Time in Seconds)

Run No.	Code 936FF	Code 936FS	Code 936FT	Code 9362
1	8.3	7.3	5.5	6.1
2	8.2	7.5	5.7	5.3
3	8.7	7.3	5.7	5.5
4	8.0	7.3	5.5	5.5
5	7.9	7.5	5.5	5.3
6	8.1	7.1	5.7	5.5
7	8.0	7.1	5.7	5.1
8	8.3	7.3	5.7	5.7
9	8.1	7.1	5.5	5.5
10	8.1	7.1	5.5	5.7
11	8.1	7.1	5.9	5.7
12	8.2	7.1	5.5	5.7
13	7.9	7.1	5.5	5.4
14	8.1	6.7	5.5	5.1
15	8.1	7.1	5.7	5.1
16	7.9	7.1	5.7	5.3
17	8.1	7.3	5.6	5.7
18	8.0	7.2	5.5	5.7
19	8.2	7.1	5.5	5.5
20	8.1	7.1	5.7	5.4

APPENDIX C

Seal Stress Data

APPENDIX C

Sealing Stresses (Coil)

(Measured in Degrees of Retardation)

0%		2%		3%		4%	
Tens. -	Comp.	Tens. -	Comp.	Tens. -	Comp.	Tens. -	Comp.
3	12	9	17	10	15	4	11
3	10	2	14	6	13	9	14
3	16	8	12	6	16	3	14
4	10	2	14	10	15	4	11
4	16	5	11	8	14	7	12
3	8	9	17	8	13	9	12
3	12	8	11	6	9	7	11
0	12	6	12	10	16	6	14
1	14	5	14	7	14	6	12
3	13	6	12	10	14	6	11
1	11	7	14	6	12	4	11
0	12	5	14	7	9	7	11
3	12	7	14	5	13	6	12
4	9	6	14	6	17	7	11
1	14	6	12	6	14	4	11
4	14	8	12	10	12	7	14
1	13	5	13	5	15	7	12
3	11	8	12	10	13	6	11
4	12	6	14	8	14	5	11
3	10	6	12	7	13	6	11

APPENDIX C

Sealing Stresses (Coil)

(Measured in Degrees of Retardation)

936FF		936FS		936FT		9362	
Tens.	Comp.	Tens.	Comp.	Tens.	Comp.	Tens.	Comp.
9	9	10	14	2	10	8	17
6	10	10	14	9	10	9	14
6	10	10	17	9	8	8	17
9	9	10	14	7	8	10	16
8	12	10	13	9	10	9	13
6	12	10	14	7	9	9	16
6	10	10	14	7	10	5	17
8	12	10	13	8	9	8	17
6	12	9	14	9	11	9	16
7	12	8	12	6	10	10	17
7	10	9	15	7	10	9	12
4	13	10	13	6	11	8	17
6	13	10	14	6	11	6	16
7	12	10	14	11	12	8	16
5	13	9	14	9	11	8	16
6	12	9	16	8	8	8	17
6	13	9	13	9	8	6	14
6	12	9	12	8	12	9	12
6	12	10	15	6	11	8	16
7	13	10	12	8	12	8	16

APPENDIX C

Sealing Stresses

(Measured in Degrees of Retardation)

(Infrared)

936FF Tens.	936FF Comp.	936FS Tens.	936FS Comp.	936FT Tens.	936FT Comp.	9362 Tens.	9362 Comp.
11	18	6	10	5	14	10	14
17	16	10	12	5	16	6	13
16	14	6	14	8	16	7	17
24	7	9	18	7	15	6	12
5	18	6	14	4	9	8	12
10	21	6	14	8	14	4	20
13	16	2	14	7	12	12	17
8	21	9	16	5	9	9	19
12	18	7	18	8	16	11	16
9	21	6	14	7	13	6	22

APPENDIX D

Creep Test Data

APPENDIX D - Table I

Creep Test Data

0% to 4% Total Iron

(Resistance Heating)

Group	Load	Time	Quantity	Rejects	% Rejects
0%	3#	3 min.	10	0	0
2%	3#	3 min.	10	0	0
3%	3#	3 min.	10	0	0
4%	3#	3 min.	10	0	0
0%	5#	3 min.	10	0	0
2%	5#	3 min.	10	0	0
3%	5#	3 min.	10	0	0
4%	5#	3 min.	10	0	0
0%	7#	3 min.	10	0	0
2%	7#	3 min.	10	0	0
3%	7#	3 min.	10	0	0
4%	7#	3 min.	8	2	25%

APPENDIX D - Table 2

Creep Test Data

3% Total Iron - Varying Reduction

(Resistance Heating)

Group	Load	Time	Quantity	Rejects	% Rejects
936FF	3#	3 min.	10	0	0
936FS	3#	3 min.	10	0	0
936FT	3#	3 min.	10	0	0
9362	3#	3 min.	10	0	0
936FF	5#	3 min.	10	0	0
936FS	5#	3 min.	10	0	0
936FT	5#	3 min.	10	0	0
9362	5#	3 min.	10	0	0
936FF	7#	3 min.	10	3	30%
936FS	7#	3 min.	10	0	0
936FT	7#	3 min.	10	0	0
9362	7#	3 min.	10	2	20%

APPENDIX D - Table 3

Creep Test Data

2% to 4% Total Iron

(Infrared Heating)

Group	Load	Time	Quantity	Rejects	% Rejects
2%	3#	3 min.	10	0	0
3%	3#	3 min.	10	0	0
4%	3#	3 min.	10	0	0
2%	5#	3 min.	10	0	0
3%	5#	3 min.	10	0	0
4%	5#	3 min.	10	0	0
2%	7#	3 min.	10	0	0
3%	7#	3 min.	10	0	0
4%	7#	3 min.	10	0	0

APPENDIX D - Table 4

Creep Test Data

3% Total Iron - Varying Reduction

(Infrared Heating)

Group	Load	Time	Quantity	Rejects	% Rejects
936FF	3#	3 min.	10	0	0
936FS	3#	3 min.	10	0	0
936FT	3#	3 min.	10	0	0
9362	3#	3 min.	10	0	0
936FF	5#	3 min.	10	0	0
936FS	5#	3 min.	10	0	0
936FT	5#	3 min.	10	0	0
9362	5#	3 min.	10	0	0
936FF	7#	3 min.	10	0	0
936FS	7#	3 min.	10	1	10%
936FT	7#	3 min.	10	0	0
9362	7#	3 min.	10	0	0

A P P E N D I X E

Statistical Analysis

APPENDIX E - Table 1

Sealing Time

0% to 4% Total Iron

(Resistance Coil)

% Iron	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
0	37.59	1.00	1.008	-	-	-	-	-	-
2	26.14	0.74	0.549	1.9	41.3[d]	-	-	-	-
3	24.32	0.70	0.487	2.1	48.5[d]	1.1	6.8[d]	-	-
4	25.87	0.42	0.177	5.7[c]	48.3[d]	3.1[b]	1.4	2.8[a]	8.5[d]

NOTE:

(a) Significant at 2.5% probability level.

(b) Significant at 1.0% probability level.

(c) Significant at 0.5% probability level.

(d) Significant at 0.1% probability level.

APPENDIX E - Table 2

Sealing Time

3% Total Iron - Varying Reduction

(Resistance Coil)

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
936FF	26.77	0.52	0.27	-	-	-	-	-	-
936FS	25.45	0.49	0.24	1.12	8.2[d]	7	-	-	-
936FT	24.09	0.48	0.23	1.17	16.9[d]	1.04	8.9[d]	-	-
9362	24.48	0.69	0.47	1.74	12.0[d]	1.96	5.2[d]	2.04	2.1

NOTE:

(d) Significant at 0.1% probability level. None of F tests indicate significant differences.

APPENDIX E - Table 3

Sealing Time

0% to 4% Total Iron

(Infrared)

% Iron	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t
0%	-	-	-	-	-	-	-
2%	8.39	0.12	0.14	-	-	-	-
3%	6.99	0.24	0.58	4.13[c]	23.3[d]	-	-
4%	7.12	0.15	0.24	1.71	28.8[d]	2.41[a]	2.0

NOTE:

(a) Significant at 5% probability level.

(c) Significant at 0.5% probability level.

(d) Significant at 0.1% probability level.

APPENDIX E - Table 4

Sealing Time

3% Total Iron - Varying Reduction

(Infrared)

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
936FF	8.12	0.17	0.03	-	-	-	-	-	-
936FS	7.18	0.17	0.03	1.0	17.1[d]	-	-	-	-
936FT	5.61	0.12	0.01	3.0[b]	56.0[d]	3.0	34.9[d]	-	-
9362	5.49	0.25	0.06	2.0	39.1[d]	2.0	23.5[d]	6.0[d]	2.0

NOTE:

(b) Significant at 1% probability level.

(d) Significant at 0.1% probability level.

APPENDIX E - Table 5

Sealing Stress

0% to 4% Total Iron

(Resistance Coil)

Tension

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
0%	2.55	1.36	1.84	-	-	-	-	-	-
2%	6.20	1.94	3.75	2.03	$6.9^{(d)}$	-	-	-	-
3%	7.55	1.85	3.42	1.85	$9.8^{(d)}$	1.09	2.25	-	-
4%	6.00	1.62	2.63	1.43	$7.3^{(d)}$	1.30	0.35	1.3	2.8

Compression

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
0%	12.05	2.11	4.47	-	-	-	-	-	-
2%	13.25	1.54	2.36	1.89	2.0	-	-	-	-
3%	13.55	2.04	4.16	1.08	$2.3^{(a)}$	1.76	0.5	-	-
4%	11.85	1.18	1.40	$3.20^{(a)}$	0.4	1.68	$3.3^{(b)}$	2.96	$3.2^{(b)}$

NOTE:

(a) Significant at 5% probability level.

(b) Significant at 1% probability level.

(d) Significant at 0.1% probability level.

APPENDIX E - Table 6

Sealing Stress

3% Total Iron - Varying Reduction

(Resistance Coil)

Tension

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
936FF	6.55	1.23	1.52	-	-	-	-	-	-
936FS	9.60	0.60	0.36	4.2(d)	9.8(d)	-	-	-	-
936FT	7.55	1.88	3.52	2.3(a)	2.0	9.8(d)	4.7(d)	-	-
9362	8.15	1.27	1.61	1.1	4.0(d)	4.5(d)	4.6(d)	2.2	1.2

Compression

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t	F	t
936FF	11.6	1.36	1.84	-	-	-	-	-	-
936FS	13.9	1.27	1.61	1.1	5.5(d)	-	-	-	-
936FT	10.1	1.36	1.84	1.0	3.5(b)	1.1	9.1(d)	-	-
9362	15.6	1.67	2.78	1.5	8.3(d)	1.7	3.6(d)	1.7	11.4(d)

NOTE:

(a) Significant at 5% probability level.

(b) Significant at 1% probability level.

(d) Significant at 0.1% probability level.

APPENDIX E - Table 7

Sealing Stress

0% to 4% Total Iron

(Infrared)

Tension

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t
2%	8.3	1.57	2.46	-	-	-	-
3%	8.0	1.41	2.00	1.23	0.45	-	-
4%	5.6	2.46	6.04	2.45	2.93 (c)	3.02	2.66 (b)

Compression

Group	$\bar{x}$	σ'	$(\sigma')^2$	F	t	F	t
2%	12.1	1.85	3.43	-	-	-	-
3%	14.3	2.16	4.69	1.37	2.45 (a)	-	-
4%	13.2	2.66	7.07	2.06	1.07	1.51	1.01

NOTE:

(a) Significant at 5% probability level.

(b) Significant at 2.5% probability level.

(c) Significant at 1% probability level.

APPENDIX E - Table 8

Sealing Stress

3% Total Iron - Varying Reduction

(Infrared)

Tension

Group	$\bar{x}$	σ'	(σ')^2	F	t	F	t	F	t
936FF	12.5	5.4	29.2	-	-	-	-	-	-
936FS	6.4	1.5	2.3	12.7(d)	3.5(c)	-	-	-	-
936FT	6.7	2.3	5.1	5.7(c)	3.1(c)	2.2	0.35	-	-
9362	7.9	2.6	6.5	4.5(b)	2.4(a)	2.8	1.6	1.3	1.1

Compression

Group	$\bar{x}$	σ'	(σ')^2	F	t	F	t	F	t
936FF	17.0	4.2	18.0	-	-	-	-	-	-
936FS	13.4	2.7	7.2	2.5	2.3(a)	-	-	-	-
936FT	14.4	2.5	6.0	3.0(a)	1.7	1.2	0.9	-	-
9362	16.2	3.5	12.0	1.5	0.5	1.7	2.0	2.0	1.3

NOTE:

(a) Significant at 5% probability level.

(b) Significant at 2.5% probability level.

(c) Significant at 1% probability level.

(d) Significant at 0.1% probability level.

APPENDIX F

Cost Comparison Data

TABLE 1

SINGLE ENDED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000'S)
Product: 237B Sealed Contact

Description		0	1	2	3	4 to 15
Machinery						
(X) machines @ approx $200						
1966		1800.0	495.0	495.0	495.0	
1967		400.0	0	111.2	111.2	—
1968		800.0	0	0	224.8	
	TOTAL	3000.0	495.0	606.2	831.0	831.0
Tools		0	0	0	0	0
Furniture & Fixtures		0	0	0	0	0
Engineering Expense		0	0	0	0	0
Floor Space (approx. $5/sq. ft./yr.)						
120 sq. ft./mach.						
1966		5.4	5.4	5.4	5.4	
1967		1.2	0	1.2	1.2	
1968		2.4	0	0	2.4	
	TOTAL	9.0	5.4	6.6	9.0	9.0
Fixed Maintenance $15,360/machine						
	TOTAL	138.2	168.9	230.3	230.3	230.3
Other Misc. Expense $3.0/machine						
	TOTAL	2.7	2.7	3.3	4.5	4.5
Salvage		0	0	0	0	0

TABLE 2

SINGLE ENDED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000'S)
Product: 237B Sealed Contact

Year	Annual Totals	Discount Factor	Present Worth
0	0	0	0
1	641.3	.870	557.9
2	785.0	.756	593.5
3	1074.8	.658	707.2
4	1074.8	.572	614.8
5	1074.8	.497	534.2
6	1074.8	.432	464.3
7	1074.8	.376	404.1
8	1074.8	.327	351.5
9	1074.8	.284	305.2
10	1074.8	.247	265.5
11	1074.8	.215	231.1
12	1074.8	.187	201.0
13	1074.8	.163]	175.2
14	1074.8	.141	151.5
15	1074.8	.123	132.2

Total Present Worth..5689.2

Annuity Factor for Number of Years in Study Period
(App. A, Col. (b) -20%)........... .171

Equivalent Level Annual Value of Fixed Investment Charges and
Other Fixed Expenses (Total x Annuity Factor)......972.9

TABLE 1.

DOUBLE-ENDED INFRARED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000'S)
Product: 237B Sealed Contact

Description		0	1	2	3	4 to 15
Machinery						
x machines approx. $235						
1966		940.0	258.5	258.5	258.5	
1967		470.0	0	130.6	130.6	
1968		235.0	0	0	66.0	
	TOTAL	1645.0	258.5	389.1	455.1	455.1
Tools		0	0	0	0	0
Furniture & Fixtures		0	0	0	0	0
Engineering Expense	TOTAL	200.0	34.2	34.2	34.2	34.2
Floor Space (Approx. $5.00/ sq. ft./yr.) 135 sq. ft./machine	TOTAL	2.7	4.1	4.8	4.8	4.8
Fixed Maintenance 163.60/machine	TOTAL	0	65.4	98.1	114.5	114.5
Other Misc. Expense $2.24/machine	TOTAL	0	.9	1.4	1.6	1.6
Salvage		0	0	0	0	0

TABLE 2

DOUBLE-ENDED INFRARED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000's)
Product: 237B Sealed Contact

Year	Annual Totals	Discount Factor	Present Worth
0	0	0	0
1	361.7	.870	314.7
2	526.9	.756	398.3
3	610.2	.658	401.5
4	610.2	.572	349.0
5	610.2	.497	303.3
6	610.2	.432	263.6
7	610.2	.376	229.4
8	610.2	.327	199.5
9	610.2	.284	173.3
10	610.2	.247	150.7
11	610.2	.215	131.2
12	610.2	.187	114.1
13	610.2	.163	99.5
14	610.2	.141	86.0
15	610.2	.123	75.1

Total Present Worth 3289.2

Annuity Factor for Number of Years in Study Period.......... .171

Equivalent Level Annual Value of Fixed Investment Charges and Other Fixed Expenses (Total x Annuity Factor).... 562.5

TABLE 1

8 HEAD INFRARED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000'S)
Product: 237B Sealed Contact

Description		0	1	2	3	4 to 15
Machinery x machines						
1966		500.0	137.5	137.5	137.5	0
1967		150.0	0	41.7	41.7	0
1968		150.0	0	0	42.2	0
	TOTAL	800.0	137.5	179.2	221.4	221.4
Tools		0	0	0	0	0
Furniture & Fixtures		0	0	0	0	0
Engineering Expense	TOTAL	200.0	34.2	34.2	34.2	34.2
Floor Space (Approx. $5.00/ sq. ft./machine)	TOTAL	3.0	3.9	4.8	4.8	4.8
Fixed Maintenance 150/machine		56.8	73.8	90.8	90.8	90.8
Other Misc. Expense	TOTAL	1.5	2.0	2.4	2.4	2.4
Salvage		0	0	0	0	0

TABLE 2

8 HEAD INFRARED MACHINE

Analysis of Investment Charges and Other Expenses
Fixed Investment Charges and Other Fixed Expenses
(in $000'S)
Product: 237B Sealed Contact

Year	Annual Totals	Discount Factor	Present Worth
0	0	0	0
1	233.0	.870	202.7
2	293.1	.756	221.6
3	353.6	.658	232.7
4	353.6	.572	202.3
5	353.6	.497	175.7
6	353.6	.432	152.8
7	353.6	.376	133.0
8	353.6	.387	115.6
9	353.6	.284	100.4
10	353.6	.247	87.3
11	353.6	.215	76.0
12	353.6	.187	66.1
13	353.6	.163	57.6
14	353.6	.141	49.9
15	353.6	.123	43.5

Total Present Worth..1917.2

Annuity Factor for Number of Years in Study Period.......... .171

Equivalent Level Annual Value of Fixed Investment Charges and Other Fixed Expenses (Total x Annuity Factor)..... 327.8

BIBLIOGRAPHY

Weyl, W. A. , Coloured Glasses, Dawson's of Pall Mall, London, 1959

Shand, E. B., Glass Engineering Handbook, McGraw-Hill Book Company New York, 1958

Kohl, W. H., Materials and Techniques for Electron Tubes, Reinhold Publishing Corporation, 1960

Hoover, H. L., Glass for Control of Infrared Radiation, EDN, a Channers Publication, May 1965

Tribble, R.M., Ferrous Oxide Glass, WE Engineer, April 1965

Eleftherion, M.P., Ferrous Oxide Doped Glass status Report #1 and #2, Western Electric Company, 1964-1965

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